CHEST

Commentary

PATIENT SAFETY FORUM

# Translational Educational Research

## A Necessity for Effective Health-care Improvement

*William C. McGaghie, PhD; S. Barry Issenberg, MD; Elaine R. Cohen, MEd; Jeffrey H. Barsuk, MD; and Diane B. Wayne, MD*

**Medical education research contributes to translational science (TS) when its outcomes not only impact educational settings, but also downstream results, including better patient-care practices and improved patient outcomes. Simulation-based medical education (SBME) has demonstrated its role in achieving such distal results. Effective TS also encompasses implementation science, the science of health-care delivery. Educational, clinical, quality, and safety goals can only be achieved by thematic, sustained, and cumulative research programs, not isolated studies. Components of an SBME TS research program include motivated learners, curriculum grounded in evidence-based learning theory, educational resources, evaluation of downstream results, a productive research team, rigorous research methods, research resources, and health-care system acceptance and implementation. National research priorities are served from translational educational research. National funding priorities should endorse the contribution and value of translational education research.**

***CHEST 2012; 142(5):1097–1103***

**Abbreviations:** AHRQ = Agency for Healthcare Research and Quality; CSI = complex service intervention; IS = implementation science; MICU = medical ICU; NIH = National Institutes of Health; SBME = simulation-based medical education; TS = translational science

Translational science (TS) has been defined historically within the biomedical disciplines. The traditional TS definition involves research that progresses from bench to bedside in three phases. T1 science involves basic laboratory discoveries in the biomedical sciences. T2 science aims to produce evidence of T1 effectiveness at the individual patient level, compare the success of different treatments to identify "the right treatment for the right patient in the right way at the right time," and translate these results into practice guidelines for patients, clinicians, and policy makers.[1] T3 science addresses health-care delivery, community engagement, and preventive services that produce measureable improvements in the health of individuals and society.[1]

The biomedical TS imperative has been expressed for at least a century. In his 1905 Nobel Prize lecture titled "The Current State of the Struggle Against Tuberculosis,"[2] Robert Koch was prescient about the slow pace of medical TS. Koch complained that the etiology of TB "shared the fate of so many similar cases in medicine, where a long time has also been necessary before old prejudices were overcome and the new facts were acknowledged to be correct by physicians."[2]

TS and comparative effectiveness research policies in the United States have been published using a "roadmap" metaphor by the US National Institutes of

Manuscript received January 17, 2012; revision accepted June 1, 2012.

**Affiliations:** From the Center for Education in Medicine and Department of Preventive Medicine (Dr McGaghie) and Department of Medicine (Ms Cohen and Drs Barsuk and Wayne), Northwestern University Feinberg School of Medicine, Chicago, IL; and the Michael S. Gordon Center for Research in Medical Education and Department of Internal Medicine (Dr Issenberg), University of Miami Miller School of Medicine, Miami, FL.

**Funding/Support:** Dr McGaghie is funded by the Jacob R. Suker, MD, Professorship in Medical Education from Northwestern University and by the US National Center for Research Resources, US National Institutes of Health [Grant UL 1 RR 025741].

**Correspondence to:** William C. McGaghie, PhD, Center for Education in Medicine, Northwestern University Feinberg School of Medicine, 1-003 Ward Bldg, 303 E Chicago Ave, Chicago, IL 60611-3008; e-mail: wcmc@northwestern.edu



**DOI: 10.1378/chest.12-0148**

Health (NIH)[3,4] and the Institute of Medicine.[5] Complementary work by the US Agency for Healthcare Research and Quality (AHRQ) outlines health-care research priorities.[6] Other publications describe the mission and goals of the NIH/National Center for Research Resources Clinical and Translational Science Awards program,[7-9] which are "to transform the conduct of biomedical research in the United States by speeding the translation of scientific discoveries into useful therapies and then developing methods to ensure that those therapies reach patients who need them most."[8] A parallel definition states that "translational research fosters the multidirectional and multidisciplinary integration of basic research, patient-oriented research, and population-based research, with the long-term aim of improving the health of the public."[10]

All of these statements about TS policies and priorities focus on biomedical research, education of biomedical scientists, and conventional treatment options. They do not address the value of a skilled workforce in the clinical medical and health professions and the importance of rigorous clinical education for the delivery of effective health care. We assert that human capital, embodied in competent physicians and other health professionals, is an essential feature of TS even though NIH, Institute of Medicine, and AHRQ policies and priorities are silent about the contribution of clinical medical education to health-care delivery.

## Medical Education Simulation as TS

Simulation-based medical education (SBME) complements biomedical TS. SBME contributes to TS when it stretches the outcome measurement end point from the simulation education laboratory and in situ teaching settings to better health-care delivery and patient outcomes, just like its biomedical counterparts.[11,12] SBME TS demonstrates, for example, that acquisition of central venous catheter insertion skills by medical residents to mastery standards achieved in the simulation laboratory (T1 science)[13] transfers to improved patient-care practices (ie, fewer needle passes, arterial punctures, needle adjustments, higher success rates [T2 science]),[14] and improved patient outcomes (ie, an 85% reduction in medical ICU [MICU] catheter-related bloodstream infection rates due to the educational intervention [T3 science]).[15] Other examples of translational outcomes resulting from SBME include skill and knowledge retention over time[16]; unexpected, yet welcome, collateral effects that document systemic educational improvement among internal medicine residents due to rigorous training of prior resident cohorts[17]; and cost-effectiveness expressed as return on financial investment.[18]

The science of health professions education underlies all three phases of the TS model. It produces human capital embodied in an informed, skillful, and ethical workforce of scientists and health professionals who work as individuals and teams. Educational science findings prescribe that many hours of focused deliberate practice[19] combined with rigorous assessment, feedback, and task repetition under controlled domain-specific conditions[20] are needed for the initial acquisition of scientific or clinical expertise and to enhance continued development of performance.[19] Educational science is the core of TS, because it produces, sustains, and enriches successive generations of scientists and professionals who advance research and patient care.

SBME, which is different from traditional clinical education because of standardization and a focus on learners rather than patients, is well suited to help physicians acquire a broad range of competencies. The best evidence now available shows that effective SBME has many of the following key features: (1) feedback to individuals and teams, (2) deliberate practice, (3) curriculum integration, (4) outcome measurement, (5) simulation fidelity that resembles the authentic educational professional context, (6) addresses skill acquisition and maintenance, (7) mastery learning, and (8) instructor training.[21] A recent, meta-analytic, comparative effectiveness study shows that SBME with deliberate practice is far superior to traditional "see one, do one, teach one" clinical education for the purpose of clinical skill acquisition.[22]

This article presents an amplified definition of TS, building on a commentary previously published in *CHEST*.[23] That article states, "Simulation-based training reduces medical error, enhances clinical outcomes, and reduces the cost of clinical care. It is surprising that medical simulation is not routinely integrated into the training curricula of all health-care professionals."[23] We suggest here that effective health-care TS stems from seamless and cascaded educational research programs that are thematic, sustained, and cumulative. Such research programs not only include T1-T3 studies and beyond, but also embrace implementation science.

## Implementation Science

Implementation science (IS) elaborates the customary biomedical focus of T2 and T3 research. It is a novel discipline and also the title of an open-access journal, now in its seventh volume (2012). The journal states its research focus is "the scientific study of methods to promote the systematic uptake of clinical research findings and other evidence-based practices into routine practice, and hence to improve the quality and effectiveness of healthcare. It includes the study of influences on healthcare professional and organisational behaviour."[24] This "is scientifically important because it identifies the behaviour of healthcare professionals and healthcare organizations as key sources of variance requiring improved empirical and theoretical understanding before effective interventions can be reliably achieved."[24] IS studies and seeks to overcome health-care organizational silos and barriers, pockets of cultural inertia, professional hierarchies, and financial disincentives that reduce health-care efficiency and effectiveness. In hospitals and clinics, IS addresses the science of health-care delivery.

Prominent clinician-scientists endorse the importance of IS for patient care and patient safety. To illustrate, Pronovost and colleagues[25] stated, "The paradox between health and harm partially stems from our failure to view the delivery of health care as a science." Further, "The research community appears to believe that discovery of effective therapies is the final endpoint. Few researchers are trained in the science of healthcare delivery, and incentives to undertake such research are anemic." They concluded, "Such science investigates the uncontrolled and complex world of influencing real-world clinical practice."[25]

Recent scholarship by a group of behavioral scientists in the United Kingdom led by Ray Pawson sheds practical light on IS ideas.[26,27] These scholars suggested that adoption and maintenance of an educational intervention such as an SBME curriculum to promote clinical skill acquisition (eg, ventilator patient management) that operates in a busy environment (eg, an MICU) is a complex service intervention (CSI). CSIs are difficult to plan and manage successfully, involve human error and resistance, may upend established clinical habits, and require coordination of professional and technical staff at many levels. A successful CSI in one clinical setting is very difficult to transfer uniformly to other clinical settings due to physical, organizational, and cultural differences. Pawson and colleagues reported that CSIs have seven "defining features," which are presented with research-based examples in Table 1.

An example of a CSI of interest to *CHEST* readers is the Michigan ICU project led by Peter Pronovost.[43-47]

**Table 1—*Defining Features of a CSI***

| CSIs Have Seven Defining Features[26]: | Example |
|---|---|
| 1. CSIs are theories grounded on hypotheses that link service delivery…to expected outcomes. | Improved patient-handoff procedures due to simulation-based team training leads to better and safer patient-care practices.[28] |
| 2. CSIs are active via input from individuals and groups. | Individual and team training in obstetric emergencies produce statistically and clinically significant reductions in birth complications due to shoulder dystocia (brachial plexus injury), low APGAR scores, and neonatal hypoxic-ischemic encephalopathy from oxygen deprivation.[29-31] |
| 3. CSIs have a long journey. The sequence of events forms a long implementation chain. | Creating, implementing, and sustaining a SBME TS research program in ACLS skills involved a sequence of steps over time: identify the need[32]; design, develop, and evaluate the curriculum scientifically[32]; develop and test outcome measures[33]; set standards[34]; revise curriculum to feature mastery learning[35]; evaluate immediate and long-run results in the simulation environment[36]; and evaluate outcomes during real hospital codes.[37,38] |
| 4. CSI implementation chain is often "non-linear and can even go in reverse." | Traditional clinical education does not improve moral reasoning, a key feature of professionalism, among medical students. "...students faced with increasingly clinical learning situations regressed in moral reasoning. ...changes in [moral reasoning] scores could be attributed to the education process rather than to the students' maturation in age."[39] |
| 5. CSIs are fragile...embedded in multiple social systems. | PBL has many definitions and expressions in medical education. "There are many variants of PBL. The context has at least as much effect as the method in determining the success or otherwise of PBL."[40] |
| 6. CSIs are "leaky" and prone to be borrowed and adapted. | Several recent reviews show that technology-enhanced education in the health professions is superior to conventional educational methods to produce better knowledge, skill, and behavioral outcomes. However, there are currently no "best methods" or "best uses" for technology-assisted education.[41,42] |
| 7. CSIs are open systems that feed back on themselves: "…interventions change the conditions that made them work in the first place." | Steady, unexpected improvement in CVC pretest scores among untrained residents were attributed to a growing number of mastery trained residents in the clinical environment.[17] |

ACLS = advanced cardiac life support; APGAR = appearance, pulse, grimace, activity, respiration; CSI = complex service intervention; PBL = problem-based learning; SBME = simulation-based medical education; TS = translational science.

This statewide, patient safety, and quality improvement project "attracted international attention by successfully reducing rates of central venous catheter bloodstream infections."[48] This was accomplished in > 100 participating Michigan ICUs. Reports about the Michigan project asserted that its results were achieved chiefly by implementing five evidence-based clinical recommendations from the US Centers for Disease Control and Prevention (CDC). "Four recommendations related to insertion of the catheter: hand washing, using full barrier precautions, cleaning the skin with chlorhexidine, and avoiding the femoral site when possible. The fifth recommendation was to remove unnecessary catheters."[44] Project outcomes were evaluated using observational checklists. Note that none of the recommendations mention medical education as a program feature.

A subsequent, qualitative, program evaluation coauthored by Pronovost that was grounded in IS principles was designed to reveal why the Michigan project CSI really worked. This study found that the reasons why the statewide Michigan MICU intervention produced strong results were peer and public pressure toward hospitals and their MICUs to participate and conform, reframing central venous catheter bloodstream infections as a social problem, "using several interventions [including strong doses of medical and nursing education] that functioned in different ways to shape a culture of commitment to doing better in practice," using data on infection rates as a disciplinary focus, and reliance on the "hard edges" of accountability and professional sanction.[48] This is a much deeper probe than outcomes gauged by simple checklists. A recent AHRQ policy statement, "Advancing the Science of Patient Safety,"[49] reinforces IS principles.

## Model of Simulation-Based TS

Powerful SBME TS is grounded in research programs that are thematic, sustained, and cumulative. A well-designed thematic SBME TS research program has clinical and implementation (science of health-care delivery) components, leveraging educational processes to produce measureable clinical impact.

What does it take to start and maintain such a program of simulation-based translational medical science? How can medical clinicians, medical educators, and health services researchers unite to achieve translational medical education research goals? Table 2 identifies components of a SBME translational research program. The components include (1) highly motivated health professions learners; (2) curricula grounded in education science with learning goals and objectives that promote deliberate practice, rigorous measurement, feedback, mastery

**Table 2—*Components of a SBME TS Research Program***

| Component |
|---|
| Learners |
| Health professionals in training: individuals and teams |
| Highly motivated |
| Curriculum |
| Goals and learning objectives |
| Educational activities or interventions |
| Deliberate practice |
| Rigorous measurement that yields reliable data |
| Feedback to learners |
| Improvement, more deliberate practice, more measurement |
| Minimum passing standards |
| Mastery learning |
| Valid data-based decisions about learners |
| Follow-up assessment |
| Educational resources |
| Simulators appropriate to learning objectives |
| Trained faculty |
| Space |
| Training materials |
| Training time |
| Funding to support above |
| Institutional senior leadership support |
| Evaluation of downstream results[11,12,50] |
| Improved patient-care practices |
| Patient safety |
| Improved health-care team work |
| Better patient outcomes |
| Skill and knowledge retention |
| Collateral effects |
| Cost-effectiveness or return on investment |
| Distal results: dissemination, adoption, public health impact |
| Productive research team[51-53] |
| Shared goals, common mission |
| Organization, planning, regular meetings |
| Functional diversity |
| Clear leadership (may change or rotate) |
| Shared cognition |
| High standards |
| Sustained hard work and commitment |
| Physical proximity |
| Minimize status differences *within* the team |
| Maximize status of the team |
| Shared activities that breed trust |
| Frequent attention to authorship issues |
| Research methods[54-58] |
| Methodologic rigor and variety |
| Quantitative, qualitative, and mixed-method approaches |
| Reliable data |
| Valid inferences and decisions |
| Research resources |
| Scientist-leaders and staff |
| Financing |
| Research and writing time |
| Patient records that contain reliable data |
| Health-care system acceptance and implementation[25,48,49,59-61] |
| Value and reinforce T1[a] SBME outcomes in situ |
| Advance science of health-care delivery |
| Advance science of patient safety |
| Rigorous implementation science |

SBME = simulation-based medical education; TS = translational science.
[a]T1 science involves basic laboratory discoveries in the biomedical sciences.

learning, and follow-up assessments; (3) educational resources including simulators, trained faculty, space, and training time; (4) intent to evaluate meaningful downstream results measured in different ways; (5) a research team that shares a variety of attributes that contribute to its productivity and morale; (6) reliance on rigorous quantitative, qualitative, and mixed research methods that produce reliable data that permit valid inferences and decisions; (7) sufficient research resources; and (8) a health-care system that accepts SBME trainees, values and reinforces T1 outcomes, and implements the program scientifically.

## Opportunities in Translational Education Research

Medical education research directed toward TS goals can address a variety of specific aims. Research opportunities focused on SBME include studies on the duration and intensity of deliberate practice, measurement development and refinement, skill maintenance, faculty development, and many others.[62] Health-care improvement needs to be addressed by translational research programs with or without a foundation in simulation. Key areas needing improvement include interprofessional education and its clinical impact; clinical team training and measurement of its downstream impact on patient care, safety, and outcomes; and enhanced patient safety and quality in a variety of inpatient and outpatient settings. A guiding principle for this work was expressed at the first Research Consensus Summit of the Society for Simulation in Healthcare: “The progress of research depends on building overarching and sustainable research programs that relate individual studies with each other.”[63]

Translational education research programs would also address national research priorities and serve the national research agenda of the newly formed Patient-Centered Outcomes Research Institute.[64] The Institute’s statutory criteria for evaluating research questions include “effect on the health of individuals and populations, probability of improvability through research, effect on health care system performance, and rigorous research methods.”[64] High on the Institute’s list of research priorities is “improving health care systems.”[64] These criteria for judging patient-centered research and the priority agenda item all conform with goals of translational education research.

## Conclusions

Translational education research is one component of TS programs that also include IS to optimally serve goals of patient-care quality and safety and better patient outcomes. Several thematic, simulation-based, education research programs have already demonstrated downstream TS results. This can only be achieved when education translational research is as robust and comprehensive as basic and clinical science translational research programs. The value of SBME translational education research to contribute to US health-care goals and outcomes should be reflected in NIH and AHRQ research-funding priorities.

## Acknowledgments

**Financial/nonfinancial disclosures:** The authors have reported to *CHEST* that no potential conflicts of interest exist with any companies/organizations whose products or services may be discussed in this article.

**Role of sponsors:** The sponsor had no role in the design of the study, the collection and analysis of the data, or in the preparation of the manuscript.

## References

1. Dougherty D, Conway PH. The “3T’s” road map to transform US health care: the “how” of high-quality care. *JAMA*. 2008;299(19):2319-2321.
2. Koch R. Nobel lecture: The current state of the struggle against tuberculosis. Nobel Prize website. http://www.nobelprize.org/nobel_prizes/medicine/laureates/1905/koch-lecture.html. Accessed January 3, 2012.
3. Zerhouni E. The NIH Roadmap. *Science*. 2003;302(5642):63-72.
4. US National Institutes of Health. NIH Roadmap for Medical Research. US NIH, Division of Program Coordination, Planning, and Strategic Initiative website. http://opasi.nih.gov/documents/NIHRoadmap_FactSheet_Aug06.pdf. Accessed December 19, 2011.
5. Institute of Medicine. *Knowing What Works in Health Care: a Roadmap for the Nation*. Washington, DC: National Academies Press; 2008.
6. Agency for Healthcare Research and Quality. What is the effective health care program. Agency for Healthcare Research and Quality website. Available at: http://effectivehealthcare.ahrq.gov/index.cfm/what-is-the-effective-health-care-program1/. Accessed December 19, 2011.
7. Heller C, de Melo-Martín I. Clinical and Translational Science Awards: can they increase the efficiency and speed of clinical and translational research? *Acad Med*. 2009;84(4):424-432.
8. Califf RM, Berglund L; Principal Investigators of National Institutes of Health Clinical and Translational Science Awards. Linking scientific discovery and better health for the nation: the first three years of the NIH’s Clinical and Translational Science Awards. *Acad Med*. 2010;85(3):457-462.
9. Reis SE, Berglund L, Bernard GR, Califf RM, Fitzgerald GA, Johnson PC; National Clinical and Translational Science Awards Consortium. Reengineering the national clinical and translational research enterprise: the strategic plan of the National Clinical and Translational Science Awards Consortium. *Acad Med*. 2010;85(3):463-469.
10. Rubio DM, Schoenbaum EE, Lee LS, et al. Defining translational research: implications for training. *Acad Med*. 2010;85(3):470-475.
11. McGaghie WC. Medical education research as translational science. *Sci Trans Med.* 2010;2(19):19cm8.

12. McGaghie WC, Draycott TJ, Dunn WF, Lopez CM, Stefanidis D. Evaluating the impact of simulation on translational patient outcomes. *Simul Healthc*. 2011;6(suppl):S42-S47.
13. Barsuk JH, McGaghie WC, Cohen ER, Balachandran JS, Wayne DB. Use of simulation-based mastery learning to improve the quality of central venous catheter placement in a medical intensive care unit. *J Hosp Med*. 2009;4(7):397-403.
14. Barsuk JH, McGaghie WC, Cohen ER, O'Leary KJ, Wayne DB. Simulation-based mastery learning reduces complications during central venous catheter insertion in a medical intensive care unit. *Crit Care Med*. 2009;37(10):2697-2701.
15. Barsuk JH, Cohen ER, Feinglass J, McGaghie WC, Wayne DB. Use of simulation-based education to reduce catheter-related bloodstream infections. *Arch Intern Med*. 2009;169(15):1420-1423.
16. Barsuk JH, Cohen ER, McGaghie WC, Wayne DB. Long-term retention of central venous catheter insertion skills after simulation-based mastery learning. *Acad Med*. 2010;85(10)(Suppl):S9-S12.
17. Barsuk JH, Cohen ER, Feinglass J, McGaghie WC, Wayne DB. Unexpected collateral effects of simulation-based medical education. *Acad Med*. 2011;86(12):1513-1517.
18. Cohen ER, Feinglass J, Barsuk JH, et al. Cost savings from reduced catheter-related bloodstream infection after simulation-based education for residents in a medical intensive care unit. *Simul Healthc*. 2010;5(2):98-102.
19. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med*. 2004;79(suppl 10):S70-S81.
20. Ericsson KA. Enhancing the development of professional performance: implications from the study of deliberate practice. In: Ericsson KA, ed. *Development of Professional Expertise: Toward Measurement of Expert Performance and Design of Optimal Learning Environments*. New York, NY: Cambridge University Press; 2009:405-431.
21. McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. A critical review of simulation-based medical education research: 2003-2009. *Med Educ*. 2010;44(1):50-63.
22. McGaghie WC, Issenberg SB, Cohen ER, Barsuk JH, Wayne DB. Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. *Acad Med*. 2011;86(6):706-711.
23. Aggarwal R, Darzi A. Simulation to enhance patient safety: why aren't we there yet? *Chest*. 2011;140(4):854-858.
24. About *Implementation Science*: Aims & scope. *Implementation Science* website. http://www.implementationscience.com/about. Accessed January 15, 2012.
25. Pronovost PJ, Murphy DJ, Needham DM. The science of translating research into practice in intensive care. *Am J Respir Crit Care Med*. 2010;182(12):1463-1464.
26. Pawson R, Greenhalgh T, Harvey G, Walshe K. Realist review—a new method of systematic review designed for complex policy interventions. *J Health Serv Res Policy*. 2005;10(Suppl 1):21-34.
27. Pawson R. *Evidence-Based Policy: a Realist Perspective*. Thousand Oaks, CA: Sage Publications; 2006.
28. Berkenstadt H, Haviv Y, Tuval A, et al. Improving handoff communications in critical care: utilizing simulation-based training toward process improvement in managing patient risk. *Chest*. 2008;134(1):158-162.
29. Crofts JF, Bartlett C, Ellis D, Hunt LP, Fox R, Draycott TJ. Training for shoulder dystocia: a trial of simulation using low-fidelity and high-fidelity mannequins. *Obstet Gynecol*. 2006;108(6):1477-1485.
30. Draycott TJ, Crofts JF, Ash JP, et al. Improving neonatal outcome through practical shoulder dystocia training. *Obstet Gynecol*. 2008;112(1):14-20.
31. Draycott TJ, Sibanda T, Owen L, et al. Does training in obstetric emergencies improve neonatal outcome? *BJOG*. 2006;113(2):177-182.
32. Wayne DB, Butter J, Siddall VJ, et al. Simulation-based training of internal medicine residents in advanced cardiac life support protocols: a randomized trial. *Teach Learn Med*. 2005;17(3):210-216.
33. Wayne DB, Butter J, Didwania A, et al. *Advanced Cardiac Life Support Checklists for Simulation-Based Education*. Washington, DC: Association of American Medical Colleges; 2009.
34. Wayne DB, Fudala MJ, Butter J, et al. Comparison of two standard-setting methods for advanced cardiac life support training. *Acad Med*. 2005;80(suppl 10):S63-S66.
35. Wayne DB, Butter J, Siddall VJ, et al. Mastery learning of advanced cardiac life support skills by internal medicine residents using simulation technology and deliberate practice. *J Gen Intern Med*. 2006;21(3):251-256.
36. Wayne DB, Siddall VJ, Butter J, et al. A longitudinal study of internal medicine residents' retention of advanced cardiac life support skills. *Acad Med*. 2006;81(suppl 10):S9-S12.
37. Wayne DB, Didwania A, Feinglass J, Fudala MJ, Barsuk JH, McGaghie WC. Simulation-based education improves quality of care during cardiac arrest team responses at an academic teaching hospital: a case-control study. *Chest*. 2008;133(1):56-61.
38. Didwania A, McGaghie WC, Cohen ER, et al. Progress toward improving the quality of cardiac arrest medical team responses at an academic teaching hospital. *J Grad Med Educ*. 2011;3(2):211-216.
39. Hren D, Marušić M, Marušić A. Regression of moral reasoning during medical education: combined design study to evaluate the effect of clinical study years. *PLoS ONE*. 2011;6(3):e17406.
40. Taylor D, Miflin B. Problem-based learning: where are we now? *Med Teach*. 2008;30(8):742-763.
41. Cook DA, Hatala R, Brydges R, et al. Technology-enhanced simulation for health professions education: a systematic review and meta-analysis. *JAMA*. 2011;306(9):978-988.
42. Jwayyed S, Stiffler KA, Wilber ST, et al. Technology-assisted education in graduate medical education: a review of the literature. *Int J Emerg Med*. 2011;4:51.
43. Pronovost PJ, Needham D, Berenholtz S, et al. An intervention to decrease catheter-related bloodstream infections in the ICU. *N Engl J Med*. 2006;355(26):2725-2732.
44. Pronovost PJ, Goeschel CA, Colantuoni E, et al. Sustaining reductions in catheter related bloodstream infections in Michigan intensive care units: observational study. *BMJ*. 2010;340:c309.
45. Pronovost PJ, Berenholtz SM, Needham DM. Translating evidence into practice: a model for large scale knowledge translation. *BMJ*. 2008;337:a1714.
46. Pronovost PJ, Berenholtz SM, Goeschel C, et al. Improving patient safety in intensive care units in Michigan. *J Crit Care*. 2008;23(2):207-221.
47. Pronovost PJ, Weast B, Rosenstein B, et al. Implementing and validating a comprehensive unit-based safety program. *J Pat Safety*. 2005;1(1):33-40.
48. Dixon-Woods M, Bosk CL, Aveling EL, Goeschel CA, Pronovost PJ. Explaining Michigan: developing an ex post theory of a quality improvement program. *Milbank Q*. 2011;89(2):167-205.
49. Shekelle PG, Pronovost PJ, Wachter RM, et al. Advancing the science of patient safety. *Ann Intern Med*. 2011;154(10):693-696.

50. Gaba DM. Where do we come from? What are we? Where are we going? *Simul Healthc*. 2011;6(4):195-196.
51. Hong L, Page SE. Groups of diverse problem solvers can outperform groups of high-ability problem solvers. *Proc Natl Acad Sci USA*. 2004;101(46):16385-16389.
52. Wuchty S, Jones BF, Uzzi B. The increasing dominance of teams in production of knowledge. *Science*. 2007;316(5827):1036-1039.
53. Salas E, Rosen MA, Burke CS, et al. The making of a dream team: when expert teams do best. In: Ericsson KA, Charness N, Feltovich PJ, Hoffman RR, eds. *The Cambridge Handbook of Expertise and Expert Performance*. New York, NY: Cambridge University Press; 2006:439-453.
54. Shadish WR, Cook TD, Campbell DT. *Experimental and Quasi-Experimental Designs for Generalized Causal Inference*. Boston, MA: Houghton Mifflin Co; 2002.
55. Côté L, Turgeon J. Appraising qualitative research articles in medicine and medical education. *Med Teach*. 2005;27(1):71-75.
56. Cresswell JW, Klassen AC, Plano Clark VL, Smith KC. *Best Practices for Mixed Methods Research in the Health Sciences*. Bethesda, MD: National Institutes of Health, Office of Behavioral and Social Sciences Research; 2011.
57. Downing SM. Reliability: on the reproducibility of assessment data. *Med Educ*. 2004;38(9):1006-1012.
58. Downing SM. Validity: on meaningful interpretation of assessment data. *Med Educ*. 2003;37(9):830-837.
59. Donaldson SI. *Program Theory-Driven Evaluation Science: Strategies and Applications*. New York, NY: Erlbaum; 2007.
60. Damschroder LJ, Aron DC, Keith RE, Kirsh SR, Alexander JA, Lowery JC. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. *Implement Sci*. 2009;4:50.
61. Bonham AC, Solomon MZ. Moving comparative effectiveness research into practice: implementation science and the role of academic medicine. *Health Aff (Millwood)*. 2010;29(10):1901-1905.
62. McGaghie WC. Research opportunities in simulation-based medical education using deliberate practice. *Acad Emerg Med*. 2008;15(11):995-1001.
63. Dieckmann P, Phero JC, Issenberg SB, Kardong-Edgren S, Ostergaard D, Ringsted C. The first research consensus summit of the Society for Simulation in Healthcare: conduction and a synthesis of the results. *Simul Healthc*. 2011;6(7)(Suppl):S1-S9.
64. Selby JV, Beal AC, Frank L. The Patient-Centered Outcomes Research Institute (PCORI) national priorities for research and initial research agenda. *JAMA*. 2012;307(15):1583-1584.